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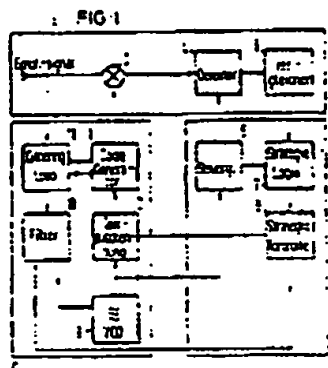
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54 Receiver for pseudorandom, phase-modulated signals

In a receiver forming part of a communications system working with pseudorandom phase-shift keying a detector with a Costas structure is used, with a connected optimizer for deciding whether pulses from the pulse-controlled pseudorandom generator in the receiver are tuned out or not. By tuning out the pulse a shift is made between the received pseudorandom sequence and the pseudorandom sequence, produced in the generator, that is to be synchronized, without detuning of the pulse frequency. The invention provides a more rapid acquisition of synchronism. A receiver designed according to the invention is for use in interference-proof spread spectrum communications systems that work with pseudorandom phase-shift keying.



## Patent Claims

1. For receiver provided for an information transmission system in which a band spread of a useful signal is produced on the transmission side by means of a pseudorandom sequence that is periodically repeating and produces phase-shift keyings in the useful signal, which receiver, for the purpose of resetting said band spread, exhibits a code generator generating identical pseudorandom sequences and thus controlling a phase-shift switch, where, for synchronization of the pseudorandom code generator, which is pulse-controlled on the receiver side, to the pseudorandom sequence contained in the received signal a code acquisition phase is first performed for initial synchronization, or after loss of synchronization, and the synchronism is thereupon maintained by a control loop, wherein a device (2) for tuning out the periodic pulse is connected to the code generator (1), by means of which device a relative motion between the two synchronized pseudorandom sequences is achieved during the acquisition phase, the received signal is fed during the acquisition phase to an in-lock detector (4) connected to the phase-shift switch (3), which in-lock detector, in accordance with the so-called Costas structure, exhibits an in-phase channel and a quadrature channel, in which channels a matched filter (15, 16), a scanning filter (17, 18), and a squaring unit (20, 21) are in each case provided in series for the purpose of integration and are connected to a summator (23), to which a comparator (5) is connected, in which comparator it is decided, should the integration output value drawn from the summator (23) exceed a predetermined threshold value, that the two pseudorandom sequences to be compared basically coincide in time, and, when the comparative threshold is not exceeded, the device (2) for tuning out the periodic pulse is immediately reswitched in the case of initial synchronization and is reswitched only after single or multiple repetition of the integration process in the

case of synchronization loss.

2. A receiver according to claim 1, wherein a product accumulator (24) is positioned between the summator (23) and the comparator (5), in which product accumulator a number of successive integration output values are accumulated and these accumulated output values are compared in the comparator (5) with a suitable raised comparative threshold for producing the outcome.

3. A receiver according to claim 1 or 2, wherein the integration time, the number of observations, and the comparative threshold are adaptive.

4. A receiver according to one of the preceding claims, wherein the realization is microprocessor-oriented.

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**A FIG 1**



**FIG 2**

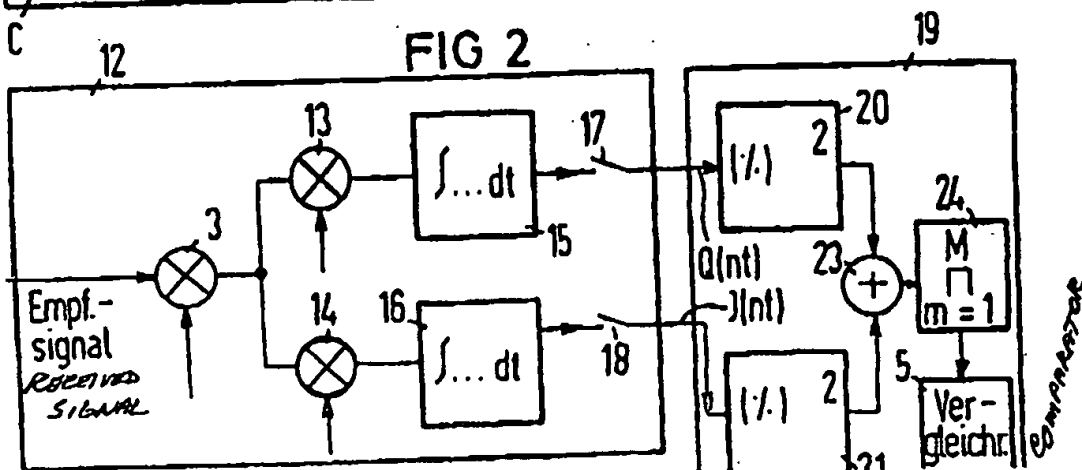
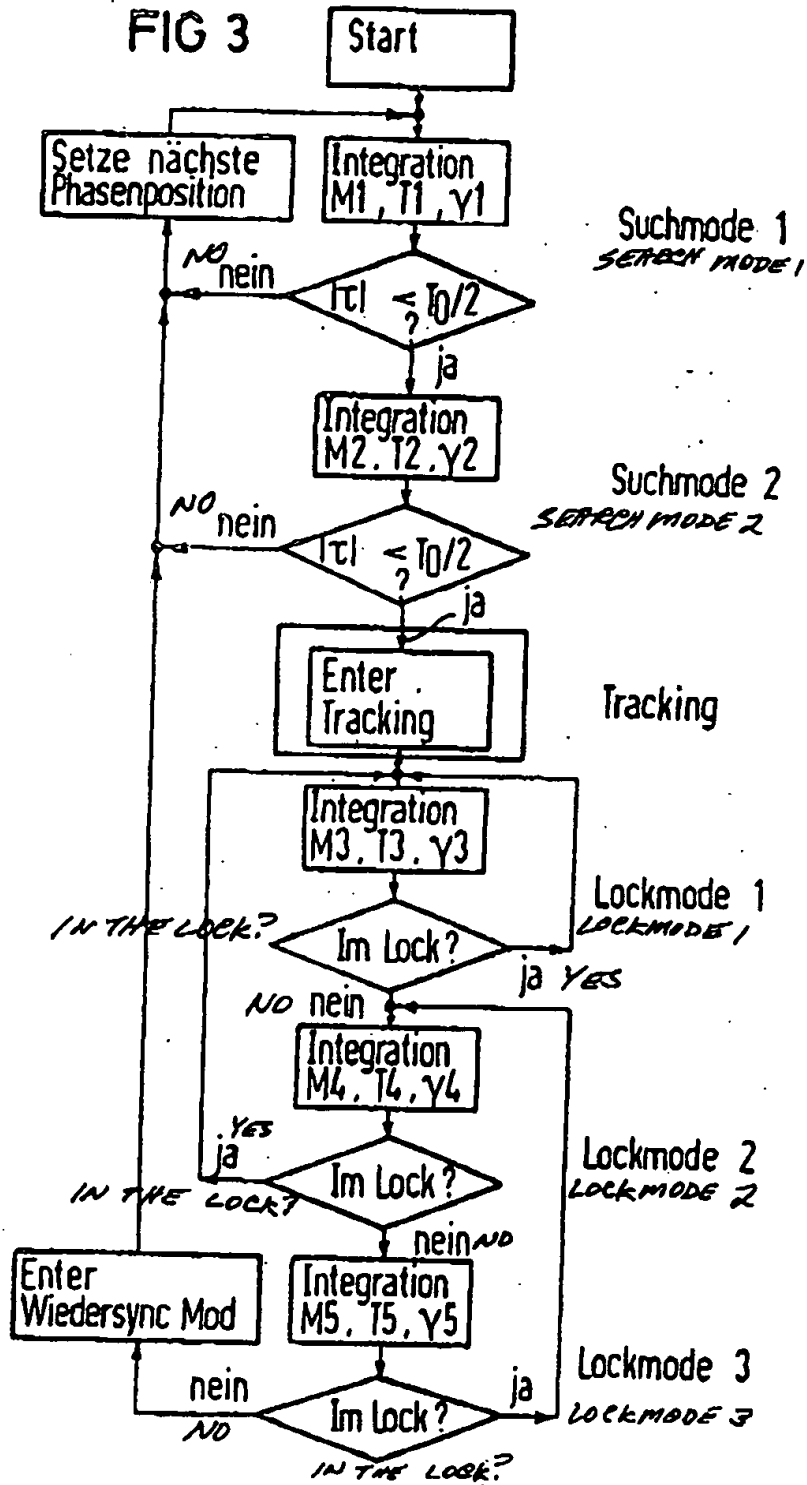


FIG 3

SET NEXT  
PHASE POSITION

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Receiver for pseudorandom, phase-modulated signals

The invention relates to a receiver provided for an information transmission system in which the band spread of a useful signal is produced on the transmission side by means of a pseudorandom sequence that is periodically repeating and produces phase-shift keyings in the useful signal, which receiver, for the purpose of resetting the band spread, exhibits a code generator generating identical pseudorandom sequences and thus controls a phase-shift switch, where, for synchronization of the pseudorandom code generator, which is pulse-controlled on the receiver side, to the pseudorandom sequence contained in the received signal a code acquisition phase is first performed for initial synchronization, or after loss of synchronization, and the synchronism is thereupon maintained by a control loop.

Synchronization of the pseudorandom generator in the receiver to the pseudorandom sequence contained in the received signal is indispensable to the functioning of the communications system. Here a distinction must be made between the acquisition phase at the beginning of transmission or after a synchronization loss and the maintenance of the synchronism after successful acquisition. Details on this relationship can be found in the article by W.P. Baier, "Considerations on interference-proof wireless communication systems", Siemens Research and Development Reports No. 4 (1975), pp. 61-67, and the book by R. C. Dixon, "Spread Spectrum Systems", New York, 1976, pp. 180-210.

For example, for the purposes of acquisition, it is known to give the receiver's pseudorandom generator a somewhat higher pulse frequency than the transmitter, until the output voltage of

a correlator has exceeded a certain threshold and then announces convergence between the two pseudorandom sequences. Various other acquisition processes are described in the articles of G.F. Sage: Serial synchronization of pseudonoise systems, IEEE Transactions on Communication Techn. Vol. COM-12, (1964) pp. 69-78; R.B. Ward: Acquisition of pseudonoise signals by sequential estimation, IEEE Transaction on Communication Techn. Vol. COM-13 (1965) pp. 475-483, and by D.P. Morgan, J.M. Hannah, J.H. Collins: Spread-spectrum synchronizer using an SAW convolver and recirculation loop, IEEE Proceedings, Vol. 65 (1976) pp. 751-753.

The goal of the invention is to create a code acquisition device for identifying a synchronism, by means of which a refined acquisition strategy can be realized, so that synchronization can be reached more rapidly than with technology known to the prior art.

According to the invention, which relates to a receiver of the type initially described, this goal is achieved in that a device for tuning out the periodic pulse is connected to the code generator, by means of which device a relative motion between the two synchronized pseudorandom sequences is achieved during the acquisition phase; in that the received signal is fed during the acquisition phase to an in-lock detector connected to the phase-shift switch, which in-lock detector, in accordance with the so-called Costas structure, exhibits an in-phase channel and a quadrature channel, in which channels a matched filter, a scanning filter, and a squaring unit are in each case provided in series for the purpose of integration and are connected to a summator, to which a comparator is connected, in which comparator it is decided, should the integration output value drawn from the summator exceed a predetermined threshold value, that the two pseudorandom sequences to be compared basically coincide in time; and in that, when the comparative threshold is not exceeded, the device for tuning out the periodic pulse is immediately

reswitched in the case of initial synchronization and is reswitched only after single or multiple repetition of the integration process in the case of synchronization loss.

If the quality of the detector is to be even further improved, a possibility for achieving this is provided by multiple observation. Here there is inserted between the summator and the comparative device a product accumulator, in which a number of integration output values following each other in succession are accumulated, so that this accumulated output value can be compared in the comparator to a suitably raised comparative threshold for achieving the outcome. With this measure the probability of detection is greater and the probability of false alarm is smaller.

The invention will next be described in greater detail on the basis of three figures.

Shown are:

- Figure 1        the block diagram of a circuit according to the invention for implementation of code acquisition in a receiver for a pseudorandom phase-modulated received signal
- Figure 2        in a block diagram the structure of an optimal in-look detector for switching according [line missing in original]
- Figure 3        a flow chart as exemplary embodiment for the acquisition strategy.

On the basis of fig. 1, code acquisition will next be described in a receiver belonging to an information transmission system in which band spreading of the useful signal is brought



about on the transmission side by means of a periodically repeating pseudorandom sequence that produces phase-shift keyings of a useful signal. In the receiver the band spread must again be cancelled, and this is performed by reswitching a phase-shift switch 3 in rhythm with a pseudorandom sequence produced by a pseudorandom generator 1. Synchronization between the pseudorandom sequence contained in the received signal and that produced in the receiver occurs in two stages. First, in a coarse acquisition the two codes are made to coincide up to about one code digit, i.e.,  $\pm T_0/2$ , where  $T_0$  is the elementary period of the pseudorandom sequence. This requires a search technique, i.e., a so-called acquisition strategy. Fine synchronization is performed in the second stage, which is realized with a control loop, for example, a delay-locked-loop or a so-called dithering loop. The transition phase from coarse acquisition to fine acquisition can also be designated as fine acquisition.

Three larger functional blocks can be identified in the block diagram according to fig. 1, namely the so-called in-lock detector A, an acquisition strategy block B, and a fine synchronization block C. The acquisition strategy block B guides and controls all operations; the in-lock detector A identifies the approximate coincidence of the two pseudorandom sequences, and the fine acquisition block C brings about the complete coherence of the two pseudorandom sequence codes.

Individually the in-lock detector A consists of the phase-shift switch 3, a detector 4, to be described later, and a comparator 5, which serves in decision-reaching. The acquisition strategy block consists of a control device 6, a device 7 for determining the strategy logic, and a strategy control device 8. The fine synchronization block C exhibits the pseudorandom generator 1, a device for pulse tune-out 2, a voltage-controlled pulse oscillator 9, a loop filter 10, and a correlation circuit 11 as part of the dithering loop.

With respect to the achievable mean acquisition time, decisive importance attaches both to the acquisition strategy and the in-lock detector A. The latter's false-alarm probability  $P_f$  and detection probability  $P_d$  determine the quality of the acquisition. Both probabilities must be carefully dimensioned due to the effect on the mean acquisition time. A choice of  $P_f$  and  $P_d$ , based on a philosophy used in radar technology, will lead to unusable results in the present case.

Results have shown that a detector with the basic structure of a Costas circuit, known from the Proceedings of the IRE, Vol. 44, (1956), no. 12, pp. 1713-1718, is expedient. Only a few additional devices are required, and some of these can be used simultaneously for other tasks in the receiver. This fortunate circumstance is highly welcome to efforts at miniaturization and the need for a reduction in expense.

Fig. 2 shows in a block diagram the structure of an optimal in-lock detector, which is designated as A in fig. 1. Only the essential functions are shown. The Costas structure can be identified in one block 12. It consists of a phase-shift switch 3, two mixers 13 and 14, in which an in-phase channel signal and a quadrature channel signal are formed, two matched filters 15 and 16, and two sampling switches 17 and 18. The basic Costas structure 12 is supplemented by an in-lock detector block 19, consisting of two squaring units 20 and 21, a summator 23, and a product accumulator 24. Positioned after the block is the comparator 5 for producing a decision.

From the sample values  $Q(nT)$  and  $I(nT)$ , which are drawn at periodic intervals of integration length  $T$  from the two matched filters 15 or 16 via the sampling switches 17 and 18, a test value  $1(nT)$  is produced by squaring in the squaring units 20, 21 and adding in the summator 23. Depending on the size of this test value in comparison to a threshold value a decision is

reached for or against the hypothesis that the two codes approximately coincide.

The quality of the detector depends on the integration length  $T$  and improves as the period  $T$  increases. The integration period  $T$  is limited at the upper end, however. In any case, the length of a bit represents its upper limit, and for the case where this symbol length is greater than the period of the pseudorandom sequence, in the acquisition phase the period of the pseudorandom sequence is the upper limit.

If, however, the quality of the detector must be further improved, the possibility of multiple observation is available. Instead of allowing the decision to be based on a single test value  $1(nT)$  in the comparator 5, a number of test values following one another in succession are accumulated in a product accumulator 24 and this product is compared with another threshold  $\delta^M$ . The larger the number  $M$  of these observations, the greater is the probability of detection, but the smaller the probability of a false alarm.

The acquisition strategy is a logical procedure through which all operations are solved and controlled. Block B in fig. 1 serves this end. The choice of strategy has an important effect on the acquisition time. Since this should be as small as possible, the integration time  $T$  of the detector A for testing a phase position of the code must be small. For the same reason, the number  $M$  of observations should also be small. On the other hand, a large integration time  $T$  with a large number  $M$  of observations increases the detection probability and lowers the false alarm probability. A small integration time  $T$  with a small number  $M$  of observations consequently results in a shorter search time, but also in a smaller probability for discovery of the right code phase position, if this occurs. Conversely, a large integration time  $T$  with a large number  $M$  of observation results

in a long search time, but a high probability of detection. These opposing effects must be optimized with respect to the desired mean acquisition time.

In the subject matter of the invention it is essential that the acquisition phase begin with a search run for the pseudorandom code without detuning of the pulse oscillator 9 in fig. 1. With the periodic tuning out of pulses by means of device 2 the necessary relative motion is achieved between the pseudorandom sequences to be synchronized. The position in time of the sequences relative to each other changes in jumping fashion by discrete intervals  $T_0$ , where the magnitude  $T_0$  corresponds to the duration of a digit in the pseudorandom sequence. This striking property in code acquisition can also be referred to as "bumping" [literally, "bumping along"]. Since this method does without detuning of the pulse oscillator 9, the intermediate frequency position of the received signal is maintained. There are also further advantages, such as high search speed or the possibility of tuning out a predetermined number of pulses. The in-lock detector A recognizes the rough agreement of the codes with a high detection probability, and the search run is interrupted.

A possible acquisition strategy is shown as an example in the flow diagram of fig. 3. Beginning with the test for the first phase position after starting, with integration  $M_1$ ,  $T_1$ ,  $\delta_1$ , a negative result leads immediately to a phase advance by tuning out the pulse and thus to the next phase position of the pseudorandom generator. An alarm, i.e., a phase offset  $|\tau| < T_0/2$ , in contrast leads to the second strategy level with integration  $M_2$ ,  $T_2$ ,  $\delta_2$ , from which a renewed alarm begins the code tracking activity, while a negative test leads back to the first strategy level (search mode 1, 2).

At the beginning of the code tracking phase, the dithering

loop is activated, in order to form the discriminator voltage for the regulator and thus a reset voltage for the fine frequency tuning of the pulse oscillator. According to the typical three to five-fold period of the control loop time constant, the complete coherence of the sequences is reached. This condition is identified by another detector, which is not described in connection with the invention.

The further course of the flow diagram of fig. 3 describes the in-lock strategy, which is dependent on in-lock detector A. The importance of this part is shown by a numerical example.

Let the integration time of the detector be 1 ms and the detection probability 0.999. Then the probability for detection of the correct phase position, assuming that it actually exists, for 1000 successive decisions (1 sec) =  $0.999^{1000}$ , which is 0.3677, and for 10 sec the probability =  $4.5 \times 10^{-5}$ . It is evident that a better in-lock strategy is necessary.

According to the flow diagram in fig. 3, a lock loss message does not immediately lead to initiation of a new search process. The strategy is comparable to a counter with three states 1, 2, and 3, with starting state 1. A lock loss increases the counter status by 1. The maximum state is 3. A positive test result decreases the counter state by 1. When counter state 3 is reached, the resynchronization mode is introduced. This is characterized by the fact that the pseudorandom sequence in the receiver is offset by a certain number of code digits using the pulse tune-out device. This done, the normal search mode is started. Beyond this strategy lies the consideration that with a lock-loss the relative displacement of the pseudorandom sequences in the received signal and the receiver can be of only limited size. The mentioned offset means that the new search mode must seek only relatively few phase positions. The time for resynchronization is thereby reduced to a fraction of the time

for initial acquisition.

A striking property of the described in-lock detector in connection with the acquisition strategy relates to the variable detector parameters at the different strategy levels. The integration time  $T$ , the number of observations  $M$ , and the threshold value  $\delta$  are adaptive ones. This brings with it a significant advantage. In the search mode, the a priori probability of a correct synchronization is small. In this case a test with a predetermined but constant false alarm probability is favorable. In the lock mode, on the other hand, the a posteriori probability for a correct synchronization is large. Here it is advantageous to lower the comparative threshold, in order to favor the most probable hypothesis. In the lock mode the time also plays a subordinate role, with the result that a larger number  $M$  of observations can be selected, so that the detection probability correspondingly increases. In lock mode 1 the number of observations is  $M_3$ , the integration time  $T_3$ , and the threshold value  $\delta_3$ . The same applies to lock modes 2 and 3, with observation number  $M_4$  or  $M_5$ , integration time  $T_4$  or  $T_5$ , and threshold value  $\delta_4$  or  $\delta_5$ .

The demanded flexibility is achieved to particular advantage with a microprocessor-oriented circuit. The expense for squaring, adding, and accumulating, as well as the threshold adaptation, can be taken over from an existing computer and its peripheral devices. Performance of the logical operation and triggering of suitable operations - thus the acquisition strategy as a part of the overall operating system - is a domain of the microprocessor, in any case. Processor-oriented realization also permits changes in strategy, without the need to modify the existing hardware. Thus differing conditions of use can be flexibly reacted to.

4 patent claims

3 figures